HOW DO THE PROPERTIES OF ALH84001 COMPARE WITH ACCEPTED CRITERIA FOR EVIDENCE OF ANCIENT LIFE?

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Criteria for Past Life: To be confident that any sample contains evidence of past life or biogenic activity one must determine beyond a shadow-of-doubt that certain well established features or biomarker signatures are present in the sample. In the case of Martian samples, the criteria for past life have not been established because if life existed on the planet, we have no way of knowing its detailed characteristics. Lacking independent evidence about the nature of possible past life on Mars, the scientific community must use, for the time being, the criteria established for ancient samples from the Earth [1,2].

(1) Do we know the geologic context of the sample; is it compatible with past life?
(2) Do we know the age of the sample and its stratigraphic location; are they understood enough to relate possible life to geologic history?
(3) Does the sample contain evidence of cellular morphology?
(4) What structural remains of colonies or communities exist within the samples?
(5) Is there any evidence of biominerals showing chemical or mineral disequilibria?
(6) Is there any evidence of stable isotope patterns unique to biology?
(7) Are there any organic biomarkers present?
(8) Are the features indigenous to the sample?

For acceptance of past life in a geologic sample, essentially all of these criteria must be met.

ALH84001 Data vs. the Established Criteria for Past Life:

How do the data from the analysis and study of ALH84001 compare to the established criteria?

(1) Geologic context: A Martian origin for ALH84001 has been shown by both its oxygen isotopic compositions [3] and trapped Martian atmospheric gases [4,5]. Although the exact Martian provenance of this igneous rock is unknown, ALH84001 does contains cracks and porosity which, based on textural microstratigraphy, clearly formed on Mars and could conceivably have harboured water-born microbial cells and colonies introduced after the rock cooled (as known on Earth, [6]). The presence of secondary carbonate globules or pancakes in cracks has been interpreted by most workers as an indication of relatively low temperature secondary mineralization by a fluid, possibly water. Thus, the most widely accepted broad geologic context of this rock is not incompatible with the presence of past life; if the secondary carbonates formed at low temperature from aqueous precipitation, their formation is completely compatible with past life, but does not require it.

(2) Age and history: The isotopic age of ALH84001 is 4.5 B.Y. and it is, therefore, a sample of the original Martian crust. The sample underwent extensive shocking around the 3.9 to 4.0 B.Y. period [5,7]. Carbonate formation occurred around the 3.9 B.Y. interval [8], shortly after the period of extensive bombardment and during a period of time when the planet had abundant water [9] and greater concentrations of atmospheric gases and higher temperatures. This corresponds to the time when life appeared and developed on Earth [10]. Evaporation of the fluids percolating through the impact-cracked surface could have resulted in the formation of carbonates [11,12]. The sample was ejected from the surface of Mars about 17 M.Y. ago and spent 11,000 years in or on the Antarctic ice sheets. We suggest that the geologic history of this rock is understood well enough to relate any possible life forms to the geologic history of Mars and to compare it to the history of life on Earth.

(3) Cellular morphologies: Some bacteria-like structures [13-15] occur in the rims of the carbonate globules which resemble in size and shape the mineralized casts of modern terrestrial bacteria and their appendages (fibrils) or by-products (extracellular polymeric substances, EPS) [16]. Other bacteriomorphs are very small but within the size limit of known nanobacteria (i.e. 50-200 nm, [17,18]). However, firm evidence that these bacteria-like structures are truely the fossilized remains of martian bacteria has not been found. Although some of the originally identified features may have been coating artifacts or weathered mineral structure artifacts, some are definitely not [16]. Some of the features in ALH84001 (e.g., filaments) are common biogenic markers on Earth. We conclude that the evidence for fossilized microbes and their products is not conclusive, but cannot be readily explained by non-biologic processes, and therefore should not be ignored.

(4) Microbial colonies: We have proposed that some of the features in ALH84001 may be the remains of biofilms and their associated microbial communities [13,14]. Biofilms are major evidence for bacterial colonies in ancient Earth rocks [19]. It is possible that some of the clusters of microfossil-like features might be colonies, although that interpretation depends on whether the individual features are truly fossilized microbes.

(5) Biominerals and disequilibria: The carbonates in ALH84001 contain a population of magnetites having a highly peaked size distribution and unusual rectangular prism shapes which are indistinguishable from some known microbially-produced terrestrial magnetite, but match no known non-biologic magnetite. Their formation can best be explained by biogenic activity and disequilibria of the iron oxidation potential in the fluid which was the source of the iron [15,20]. Other irregular

magnetite grains could be either biogenic or non-biogenic in origin. Whisker-like magnetites (<5% total magnetites in carbonate) described by [21-23] are quite different in size distribution and shape, and may have had an origin unrelated to the rectangular prisms. Nanometer-sized iron sulfides described in our original paper are also suggestive of disequilibria related to microbial activity [24] as is the elemental composition of the carbonates. Overall, the mineral assemblages in the carbonates, as well as their extreme chemical variations, are compatible with known biominerals and known disequilibria related to microbial activity on Earth, although more work needs to be done in general to distinguish true biominerals and biogenically-related chemical disequilibria from totally non-biologic minerals and disequilibria.

(6) Biologic isotopic signatures: Stable isotope patterns have shown the presence of indigenous carbon components which have isotopic signatures of -13 to -18 ‰ [25-27] which are in the direction of known biogenic carbon signatures. Additional detailed study of the carbon isotopic signatures is needed to distinguish between indigenous carbon components within ALH84001 and those introduced after its arrival on Earth. Overall, the carbon isotopic signatures of the identifiable non-terrestrial, possibly organic carbon are compatible with biologic carbon isotope fractionation, when compared with the signatures of the Martian carbonates, but do not prove that it occurred.

(7) Organic biomarkers: Possible organic biomarkers are present within ALH84001 in the form of PAHs associated with the carbonate globules [28] some of which may be a unique product of bacterial decay [29]. The distribution of the reduced carbon compounds within the globules is irregular [28,30,31]. Clemett's data on PAHs [28], combined with recent amino acid data (i.e. [32]), show that the detected PAHs are most likely indigenous to ALH84001, whereas the detected amino acids are most likely Antarctic contamination. Exhaustive data must be collected before either component can be used as a biomarker for a specific sample [33].

(8) Indigenous features: In our opinion, the recent studies of [28] have shown conclusively that the PAHs are indigenous to ALH84001 and are not contaminants. Based on isotopic compositions [25,27,34,35] and textures, there is absolutely no question or disagreement that the carbonate globules and their included minerals formed on Mars and are indigenous to the meteorite. The possible microfossil structures and some regions of organic carbon which are embedded in the carbonates are therefore almost certainly indigenous, but other possible evidence for life (e.g. amino acids) may be Antarctic contamination.

Summary:

Clearly, we have not completely satisfied all of the criteria needed for general acceptance of evidence for life in a sample. We argue that we are close on some (likely biominerals, possible organic biomarkers, indigenous features) and not so close on others (well documented geologic context, evidence for cells and colonies). However, not one of the eight criteria has been shown to be violated by any published data on ALH84001 so as to preclude life, and some evidence exists supporting each criterion. Therefore, the jury is still out on early Mars life as revealed by this meteorite [36]. Evaluation against these criteria is still in progress and more data are needed.

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